EVALUATION OF SEVERAL METHODS OF SCHEDULING AND CONDUCTING PHYSICAL INVENTORIES

by

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THESIS

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ABSTRACT

Advanced operations research procedures have provided the inventory manager a set of optimal decision rules for operating his inventory system. However, these decision rules are applied to information from inventory records that may be in error. If the records are in error the decision rules no longer insure optimal operation of the system. This paper addresses the problem of which physical inventory procedures best maintain record accuracy at a satisfactory level. Four physical inventory procedures are discussed and then tested using a Monte Carlo computer simulation of a multiple item, single warehouse, single inventory manager supply system. Discrepancies of various types are introduced into the records reflecting estimates obtained from a large naval supply center. It was found that for high demand items accuracy levels above 90 percent are not feasible. Due to the low cost per item inventoried the wall-to-wall inventory was found to be the most economical system in most situations. Suggestions are made for subsequent research.

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CHAPTER 1

INTRODUCTION

1.1 Background

Control of inventories has become more and more sophisticated. Using operations research techniques, decision rules have been formulated that dictate when to buy stock and how much to buy. Computers have been installed to implement these decision rules and to make possible better control than was thought possible only a few years ago. Unquestionably, we are now actually managing our inventories in an attempt to minimize the total variable cost of maintaining the inventory. However, procurement decisions are based on information provided by inventory records; we don't actually count the items on the shelf before implementing our decision rules. If the records accurately reflect what is in the warehouse, then these decision rules will insure optimal operation of the inventory system. However, if the records are inaccurate, regardless of our decision rules optimal operation cannot be assured. Daeschner [1] has shown that it will cost more to operate the system if the records contain errors. Thus, to operate inventory systems to the best advantage accurate records are a necessity.

Our last statement must be qualified to be perfectly correct. The optimal operation of the system requires accurate records if the cost of maintaining accurate records is less than the additional cost of operating with inaccurate records. It is conceivable that it may be more economical to operate with no physical inventories or other error controls. This possibility is introduced in [2]. However, at the present time methods of detecting and eliminating record errors are the primary concern. The meaning of "inventory record error" and possible measures

of error in inventory records are discussed by Schrady [3]. Throughout this paper the term inventory record error or discrepancy is defined as the non-agreement of the quantity of an item shown in the appropriate stock record to be available for issue with the quantity in the warehouse actually available for issue. Positive inventory record errors are defined as those where the actual on-hand quantity exceeds the record quantity; similarily, negative errors describe a condition where there is less material available for issue than the records indicate.

1.2 Approach to the Problem

The inventory model chosen for this study is a single warehouse, multi-item system operating under a budget constraint. In the model all shortages are backordered. In an attempt to model a realistic inventory system operating in the military climate, it was felt that the multi-item feature was necessary to examine the interdependencies of the items. This feature allowed us to examine budget influences as well as permitting interactions in the records such as transactions being posted to the wrong record. The simplest method of operating this model is the use of a high speed computer simulation. Daeschner [1] has developed a 100 item inventory simulation for the IBM 360 computer which will simulate five years of inventory operation in about seven minutes running time. This simulation provided the inventory system that was needed for examining the various physical inventory procedures. Using the simulation we were able to get a look at the system operating with errors in the presence of the interdependencies of a multi-item system.

1.3 Organization of this Paper

In this paper we will discuss record error growth and methods of detection and correction of record errors. Primarily we will be interested in finding the optimal physical inventory procedures and the inventory frequencies necessary to hold record error to a specified maximum amount. We define optimal here to mean the most economical physical inventory procedures. Chapter 2 provides a discussion of error growth and detection. The inventory model which we have chosen to use in our investigation of error growth is described in Chapter 3. Chapter 4 contains descriptions of four possible physical inventory procedures and the results of simulating each of the procedures for a five-year period. The inventory procedures evaluated are:

a. Wall-to-Wall (Shutdown),

b. Inventory before Ordering,

c. Inventory Frequency as a Function of Demand, and

d. Inventory Frequency as a Function of Demand and Order Frequency.

These procedures are compared and conclusions presented in Chapter 5. Chapter 6 presents suggestions for future work.

CHAPTER 2

INTRODUCTION TO ERROR GROWTH AND DETECTION

2.1 Error Growth

Discrepancies are generated in inventory records through actions which either cause physical changes in the physical quantity of material or cause changes in the record on-hand quantity. The procedures best known for introducing record errors into the system are the processes of receiving and issuing material and theft. Another less publicized procedure which often inserts errors into the system is the physical inventory itself. In fact, an investigation of the U. S. Navy Supply Research and Development Facility, Bayonne, concluded that immediately after a wall-to-wall shutdown inventory, only about 93 percent of the stock records might be correct [4]. Very little work has been done in the field of record error growth. This may be one of the reasons there has been difficulty in settling on any good physical inventory procedures. It will be shown later in this paper that information on error growth is essential if physical inventory procedures are to be optimized.

2.2 Error Discovery and Correction

Although we have implemented annual, cyclic, and biannual inventories and statistical sampling plans, error discovery has been accomplished primarily by shutdown wall-to-wall inventories. It has been conceded that if a system contains record errors the only way to find and correct them is to count every item. But we have already stated that records may be only 93 percent accurate after a complete wall-to-wall inventory. Thus it appears that more efficient inventory procedures need to be formulated and implemented.

One of the basic concepts of search theory is to find the probability distribution of your target. Using this information it is best to allocate our search effort to those areas where the highest expected number of target detections exists. If a record error is defined as our target, then the next step is to find the distribution of record errors. By proper investigation into the procedures that insert errors into our inventory records, we can compute the probability that a record is in error; i.e., if all errors are inserted by issues and the probability of inserting an error each time an issue is made is .01, then we can compute the probability that a record is in error:

$$\text{Probability record is in error} = 1-(1-.01)^n,$$

where n is the number of issues since the last inventory of that item. This equation is derived from the Bernoulli distribution where each issue is considered an independent trial with p=.01. If we assume the errors inserted during receipts are independent of those inserted during issue and set the probability of error during receipt to .02 then:

$$\text{Probability record is in error} = 1-(1-.01)^n(1-.02)^m$$

where m is the number of receipts. This model could be built up to contain any procedures that are known to insert errors. It should be noted that this model assumes the errors are not self correcting. If the system is viewed as a two-state Markov Chain where state one is an accurate record and state two is an inaccurate record, then state two is absorbing. If the reader doubts this assumption he should think of the probability of moving from state two to state one, $P_{2,1}$, as the probability that a random error will exactly cancel out all previous errors inserted in that item since the last inventory. Say an issue was made of 100 items instead of 10. Then the P2,1 is probability we insert another error (.01) times the probability that the error is to issue exactly 90 less than was requested (.000 ···).

If we wish to prevent more than a certain percentage of the records from being in error, it would be convenient to keep up with the probability that an item is in error at any given time. By using a trigger mechanism in our inventory system a physical inventory of an item could be called for whenever the probability of error for that item reached the fixed amount. This inventory would be taken only on that particular item. This special type of spot inventory should be distinguished from the complete inventory since the cost is substantially different. An estimate of the cost of inventorying an item by the two methods has been made by the Navy Fleet Material Office [5]. These estimates show that a special item inventory costs roughly three times as much as a single item inventory made as part of a wall-to-wall inventory.

Unfortunately this procedure requires us to know how and with what frequencies record errors are generated. Although this information is not readily available in most systems, good estimates could and should be made to reflect the frequency of record error generation by the various normal inventory operations. The simulation incorporated into this study used estimates of the rates of error generation provided to Daeschner [1] by the U. S. Naval Supply Center in Oakland, California. Additional guidance is available from the Naval Supply Systems Command (NAVSUP) [6] which states minimum quality rates for the major tasks in receiving, issuing, storage, and inventorying operations. For example, NAVSUP states that receipt accuracy should be .975 and issue accuracy .94. Rates used in the simulation are presented in Chapter 3.

It appears that if we are ever to control record accuracy that the first step is to isolate the error generating procedures. This information is required so that inventory managers can get at the root of the

inventory accuracy problem. Physical inventory procedures only trim back the error level to some specified height. In addition to allowing inventory managers to identify the error generating problems so that they can take appropriate actions to minimize the error growth, it will also allow physical inventory systems to make use of the trigger method described above. This hopefully will reduce the cost of holding down the error rate.

CHAPTER 3

THE INVENTORY MODEL

3.1 Basic Model

The supply system we have chosen to model operates on an issue preposting system so that material is not issued from stock unless the records indicate that some material is available for issue. This system is prevalent at stock points of the U. S. Navy and is in contrast to a postposting system in which issues are posted to stock records subsequent to the physical issue of material. Receipts are treated as being posted and made physically available for issue at the same time. The system is treated as a single inventory manager, single warehouse, multi-item system operating under a procurement budget constraint. All shortages are backordered.

Demands (simulated requisitions) are generated in accordance with a "stuttering poisson" stochastic process; that is, the time between requisition arrivals is distributed as an exponentially distributed random variable, while the quantity demanded on an individual requisition is distributed as a geometrically distributed random variable. The lead times for reorder material are assumed to be random variables, normally distributed with standard deviation equal to .29 times the mean lead time. The simulator employs two pseudorandom number generators, one for demand generation and the other for all other Monte Carlo requirements. The basic model was developed by Daeschner and is presented in detail in reference [1].

Discrepancies are introduced by Monte Carlo mechanisms in the processes of issuing and receiving material. Initially, all records agree with the actual situation. Whenever material was received, issued, or

inventoried, a pseudorandom number is generated. The value of this number determines whether an error is to be introduced and if so the size of the error and how it will be inserted. The parameters used in the Monte Carlo introduction of errors for this system were as follows:

EVENT	PROBABILITY
Receipt processed correctly	0.9600
Receipt is 6% less than documented	0.0150
Receipt is 8% more than documented	0.0150
Receipt posted to randomly selected record	0.0100
Issues processed correctly	0.9800
Failed to issue	0.0068
Overissue	0.0066
Overissue by 8%	(0.0066)(0.660)
Overissue by 18%	(0.0066)(0.250)
Overissue by 40%	(0.0066)(0.090)
Underissue	0.0066
Underissue by 6%	(0.0066)(0.660)
Underissue by 20%	(0.0066)(0.170)
Underissue by 60%	(0.0066)(.0170)

3.2 Modification of Basic Model

Since Daeschner was primarily interested in determining the costs of errors in the operation of an inventory system, his basic model had to be modified so that the four procedures for correcting records could be evaluated. In general, the modifications correct a record only after it has been physically inventoried. Although it is known that physical inventory procedures may insert errors of up to 7 percent [4] in the records, for this system we have assumed that physical inventories are

100 percent accurate when performed. Thus, it is realized that results are biased to that extent and record accuracy from the simulations is somewhat higher than in actual operation. There is one exception to this policy. The system automatically calls for a spot inventory every-time we get a warehouse refusal. We have assumed that this spot inventory will correct a record in error 97 percent of the time. It will not insert an error, but it will fail to correct the record error 3 percent of the time.

The modifications provide for the generation of information which we felt was necessary for evaluation of the various procedures for correcting errors. This consisted primarily of data on the number of inventories required and resulting average and maximum error levels.

CHAPTER 4

PHYSICAL INVENTORY PROCEDURES EXAMINED

4.1 Wall-to-Wall Inventories

4.1.1 Introduction

The wall-to-wall inventory simulated here is a 100 percent inventory of all items in the system at a given time. This procedure, which normally required a complete shutdown of service, has always formed the backbone of our physical inventory procedures. Three models were used for this analysis. The first model (Model A) kept up with the number of errors in the system and caused a complete inventory to be taken whenever the number of records in error reached a fixed limit. This allowed us to determine the number of complete inventories required to maintain at all times a record accuracy of X percent or more. This model could be used in conjunction with a statistical sampling model. Statistical sampling would be used until the sample showed the maximum allowable error rate and then the complete inventory would be conducted. This is similar to what the Army's statistical sampling procedures have moved toward.

The second model (Model B) is the scheduled periodical wall-to-wall inventory. Based on no prior information as to error rate the system is inventoried after a fixed amount of time. Both of these models assumed 100 percent accurate inventories. The third model (Model C) called for a 92.9 percent accurate inventory. This parameter was selected from the Bayonne study [4]. In this model a correct record has a 7.1 percent chance of having an error inserted by the inventory procedure itself.

4.1.2 Experiment

The three experiments which were run were designated 1A, 1B, and 1C to correspond to the models described. In experiment 1A the average number of complete physical inventories required per year was determined for record accuracy levels of 90 percent, 80 percent, 75 percent, 70 percent, 60 percent, and 50 percent.

Experiment 1B investigated the average error over a five-year period for a system with periodic inventories scheduled at 182, 365, 730, and 912 day intervals. Results from experiments 1A and 1B are the average of 3 five-year simulations run with 3 separate pseudorandom number sequences. Experiment 1C determined the number of inventories required each year to maintain a minimum record accuracy of 90 percent if the inventory procedure was only 92.9 percent accurate.

4.1.3 Results

The results of experiments 1A and 1B are summarized in Figures 1 and 2. This data is also presented in Tables I and II. The results of experiment 1C are shown in Table III. The curve in figure 1 indicates a diminishing returns phenomena as the minimum accuracy level approaches 100 percent. This is another indication that perfectly accurate records are not a realistic goal and, possibly, the 90 percent accuracy is not realistic either. Since this simulation used active, high demand items only, a simulation with a random sample of items would indicate somewhat lower frequencies. This effect would probably be offset by our assumption of 100 percent accuracy, however. In fact, experiment 1C indicates that 26 complete inventories per year would be required to maintain a minimum record accuracy of 90 percent if our inventory is only 92.9 percent accurate. Wall-to-wall inventories have historically been conducted by clerks,

warehousemen and other non-professional physical inventory personnel. The other models examined will assume full time physical inventory personnel. It is believed that more accurate inventories will result from the use of professional counters.

4.2 Inventory Before Ordering

4.2.1 Introduction

As discussed previously, it is known that a large percentage of inventory record errors are made during issues and receipts. Our first attempt to take advantage of this information is in the model discussed in 4.3 which uses a trigger mechanism based on the number of demands to determine when to inventory an item. Another way we can utilize this information is to inventory an item prior to placing an order. In addition to having the normal benefits of correcting record errors, we will delay placing the order if we find a positive error thus avoiding the buildup of inventory carried. On the other hand, if we find a negative error at this point, the order quantity can be increased and this will decrease the risk of stockout normally associated with this type error. This enables us to have more nearly correct records when the decision rules are applied as to when and how much to order.

4.2.2 Experiment

This experiment determined the average number of records in error over a five year period when the system operated as described in 4.2.1. Two runs were made. In run 1 an item was inventoried each time an order was placed for the item. In run 2 an item was inventoried every other time an order was placed. If the budget constraint prevented an order from being placed, no inventory was taken.

Percentage of Minimum Accuracy	Number of Wall-to-Wall Inventories per Year	Days Between Inventories
90	6.5	56.5
80	2.8	128.2
75	2.2	170.
70	1.8	206.6
60	1.1	322.12
50	.73	500.

TABLE I

SUMMARY OF RESULTS OF EXPERIMENT 1A

Average Error Percentage	Interval in Days Between Inventories	Wall-to-Wall per Year	Number of Item Inventories per Year (100 items)
14.98	182	2	200
24.73	365	1	100
34.06	730	1/2	50
42.66	912	2/5	40

TABLE II

SUMMARY OF RESULTS OF EXPERIMENT 1B

Percentage of Minimum Accuracy	Number of Wall-to-Wall Inventories per Year	Days Between Inventories
90	26	14.0

TABLE III

SUMMARY OF RESULTS OF EXPERIMENT 1C

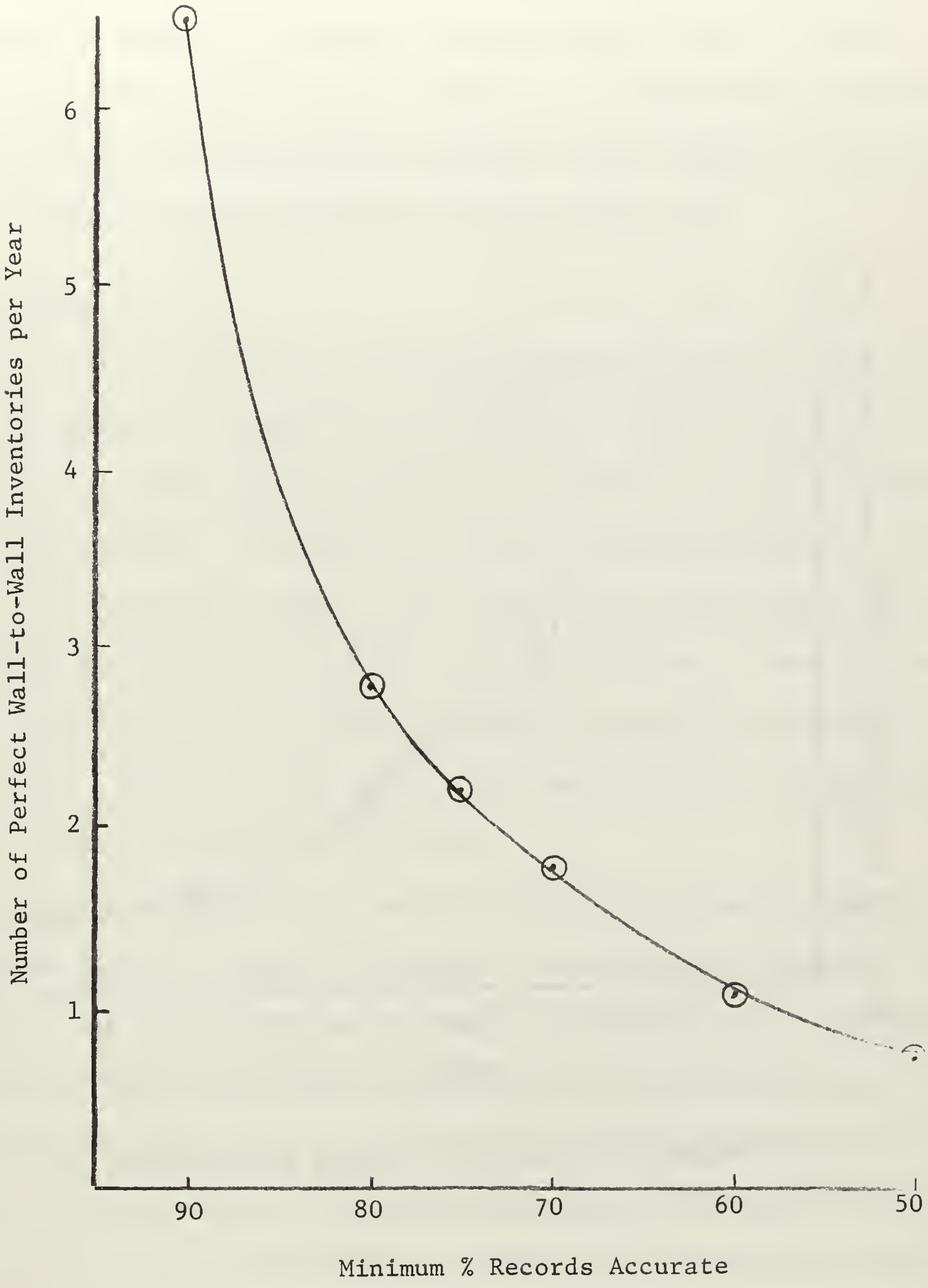

FIGURE 1. SUMMARY OF RESULTS OF EXPERIMENT 1A

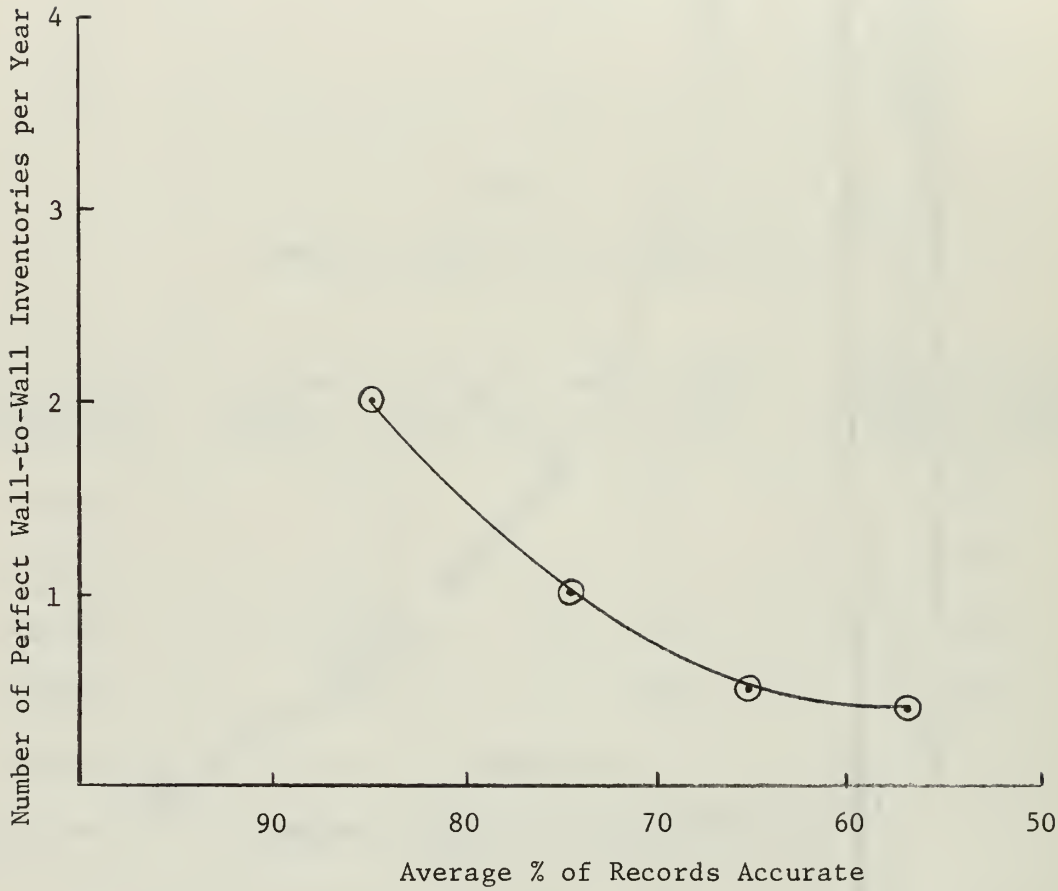

FIGURE 2. SUMMARY OF RESULTS OF EXPERIMENT 1B

Along with the average number of records in error we recorded the number of inventories required and the maximum number of records in error during the five-year period. Each run was repeated for three five-year periods with a different pseudorandom number sequence for each replication. Results were then averaged for the three runs.

4.2.3 Results

If a spot inventory is conducted everytime an order is placed, the resulting inventory system will be operating at about 90 percent record accuracy. The lowest expected accuracy during the five years of operation would be 78 percent. An average of 473 item inventories would be required per year on the 100 line items. This means that on the average each line item would have to be inventoried 4.73 times each year. When an inventory is made there is a 11.7 percent chance the record being checked in is in error. Positive errors will be discovered that will delay placing about 11 orders per year per 100 items.

If a spot inventory is conducted every other time an order is placed the inventory system will be operating at about 85 percent record accuracy. The lowest expected accuracy would be 72 percent. An average of 2.8 item inventories would be required per year per line item. When an inventory is made there is a 17.4 percent chance an error will be found. Positive errors will be discovered that will delay placing about 10 orders per year per 100 items. Again we see a diminishing returns phenomenon.

4.3 Inventory Frequency as Function of Demand

4.3.1 Introduction

We know that for this system and most other current inventory systems that the major portion of record errors are inserted as a result

of the issuing procedures. In an attempt to take advantage of this information a model was developed to make inventory frequency a function of demand frequency. In section 3.1 the chance of an error being inserted during an issue was given as .02. Thus the probability a record is in error is:

$$PRE = 1-(1-.02)^n \qquad \text{EQ 4.3.1}$$

where n is the number of demands or issues since the last item inventory. This treatment assumes that all errors are inserted by issuing actions. The model discussed in 4.4 will include order procedures as well as demand procedures as error inserting actions.

The model used for this experiment was to set a trigger that would be activated after an item receives n demands. The trigger mechanism would call for an inventory to be made on that item at that particular time.

4.3.2 Experiment

The experiment determined the average number of records in error over a five-year period when the system operated as described above. The trigger mechanisms were set at 4, 6, 8, 10, 12, 14, 16, 20, and 24 demands between inventories. Each trigger setting was then repeated for three five-year runs with different pseudorandom number sequences on the computer. Results were averaged for the three replications.

Along with the average number of records in error we recorded the number of inventories required and the maximum number of records in error during the five-year program.

4.3.3 Results

The results of this experiment are given in Table IV and Figure 3.

Trigger Number of Demands Between Inventories	Average Record Accuracy	Minimum Record Accuracy	No. Spot Inventories Required per Year (100 Items)
4	92.55	84.7	718
6	90.89	83.0	476
8	88.07	78.3	354
10	87.42	79.3	282
12	84.15	74.7	233
14	83.96	75.3	199
16	81.60	72.3	172
20	80.15	67.0	136
24	77.38	66.3	112

TABLE IV

SUMMARY OF RESULTS OF EXPERIMENT 3

It should be noted that to operate at an average record accuracy of 84 percent would require more than two inventories per item per year and accuracy could be expected to drop to 75 percent at times under this procedure. To operate at 90 percent accuracy would require more than four inventories per item per year.

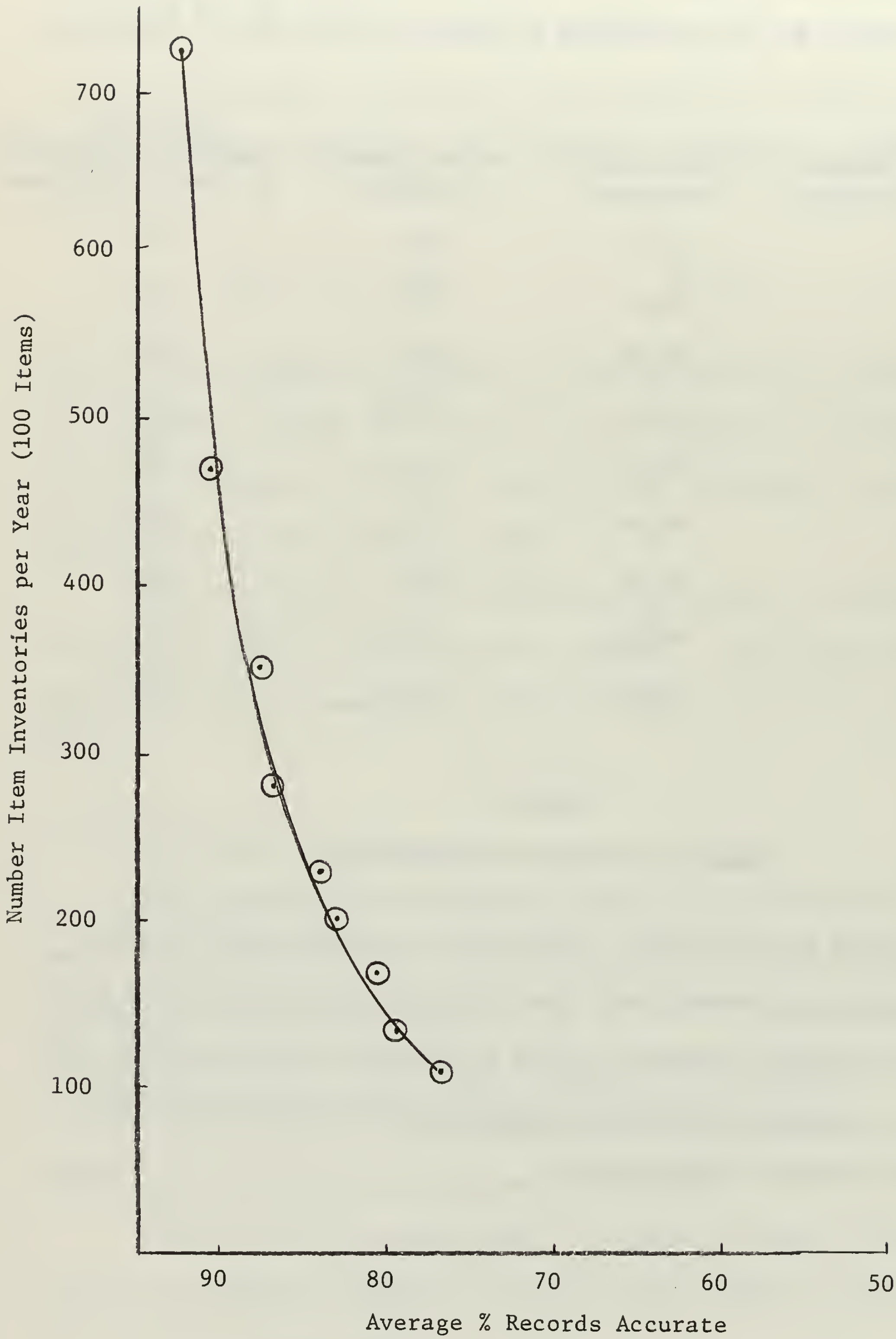

FIGURE 3. SUMMARY OF RESULTS OF EXPERIMENT 3

4.4 Inventory Frequency as Function of Demand and Order Frequency

4.4.1 Introduction

Most errors are inserted into inventory systems by issue procedures. But another critical source of errors are receipt or ordering precedures. This model modifies the previous model, see section 4.3, in such a way as to include receipt and ordering errors. As stated in paragraph 3.1, the probability that an error is made during processing orders is .04 for this model. Therefore our new probability that a record is in error is:

$$PRE = 1 - (1-.02)^{n} (1-.04)^{m} \qquad \text{EQ 4.4.1}$$

where equation 4.3.1 has been modified to take into account the errors introduced by m orders being placed and received.

This model again used a trigger as discussed in 4.3.1. However, each demand advances us only .5 units toward the trigger while each order advances us 1 full unit in accordance with the ratio .02 : .04.

4.4.2 Experiment

The trigger mechanisms were set for an item to be inventoried whenever the trigger values reached 3, 4, 6, 8, 10, 12, and 20. For example, if the trigger was set at 3 then an inventory would be made after 3 orders, 6 demands, 4 demands and 1 order, or 2 demands and 2 orders were received. Each trigger setting was repeated for three five-year runs with different pseudorandom number sequences. Results were averaged for the three replications. The same data as explained in 4.3.2 was accumulated.

4.4.3 Results

The results are summarized in Table V and Figure 4. About 3.8 inventories per item per year would be required to maintain 90 percent accuracy and 2.1 per item per year would be required to maintain 85 percent accuracy. Minimum record accuracy would be about 83 and 75 percent, respectively, for these two cases.

Trigger Setting	Average Record Accuracy	Minimum Record Accuracy	No. Inventories Required per Year (100 items)
3	91.53	84.0	481
4	89.04	78.7	359
6	85.87	76.3	236
8	81.39	70.3	175
10	79.66	69.7	138
12	76.63	64.3	112
20	69.40	57.0	65

TABLE V

SUMMARY OF RESULTS OF EXPERIMENT 4

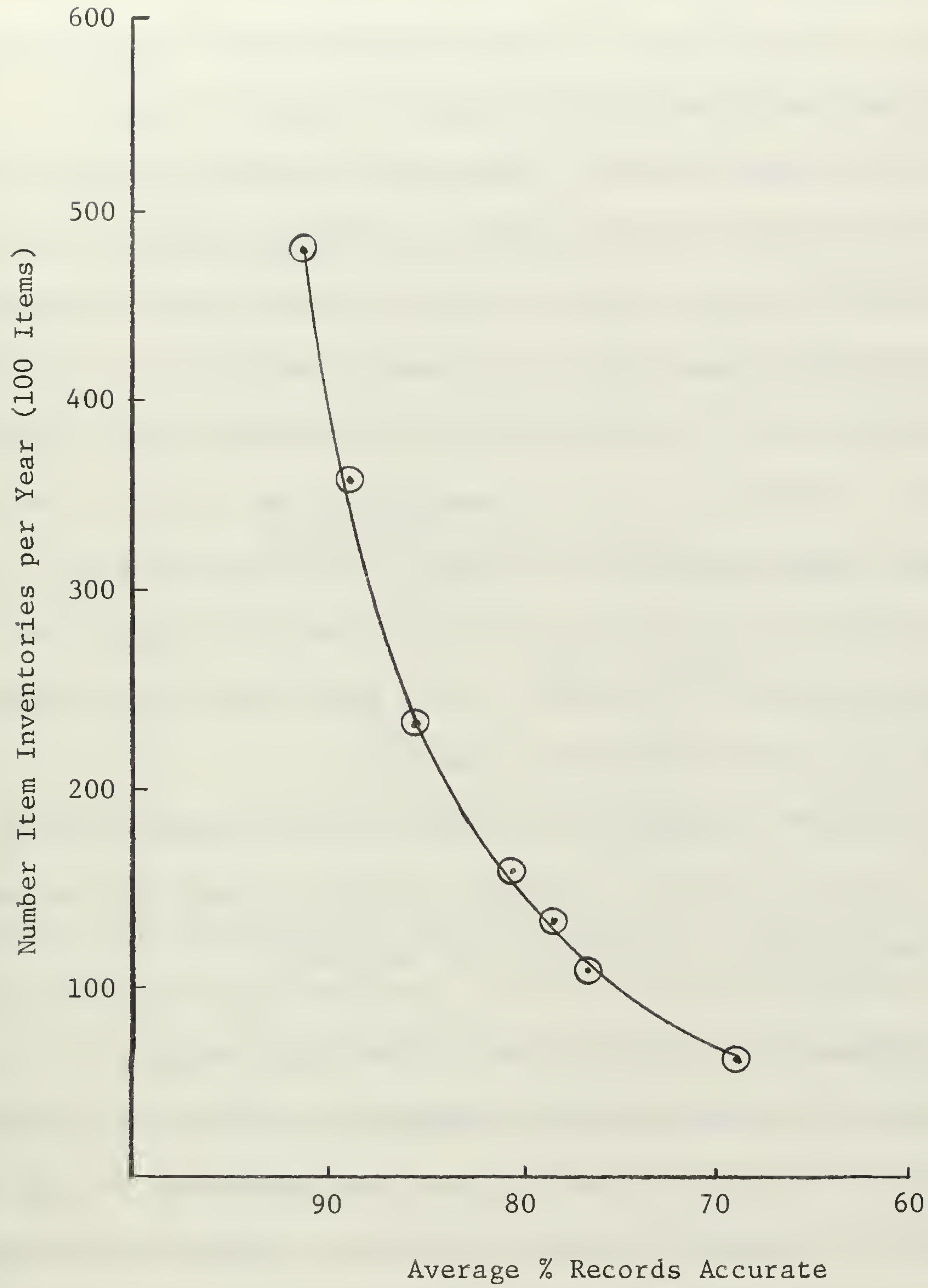

FIGURE 4. SUMMARY OF RESULTS OF EXPERIMENT 4

CHAPTER 5

OBSERVATIONS AND CONCLUSIONS

5.1 Observations

Early in this study it became clear that record accuracy figures of 90 percent were probably not realistic in light of what we have discovered about error growth. In Figure 1 it can be seen that it would require 6.5 perfect, complete, wall-to-wall inventories per year to maintain at least 90 percent record accuracy. Again it must be remembered that the simulation used active, high-demand items only. A simulation with a random sample of items would indicate somewhat lower inventory frequencies. However, failure to have 100 percent accurate inventories would tend to <u>increase</u> these frequencies. From experiment 4.1A it appears that our minimum record accuracy levels are realistically 60% and lower under present inventory procedures. This would appear to correspond to average record accuracy of about 75 percent.

The complete answer to the inventory record accuracy problem cannot be found in physical inventory procedures. More work is necessary in isolating and eliminating error generation.

5.2 Measures of Effectiveness and Decision Making

A reasonable measure of effectiveness for selecting a physical inventory procedure is the number of inventories required to hold the error rate at a specified amount. This measure of effectiveness has been selected for this study. However, it must be understood that inventory record accuracy is not a goal in itself. Supply effectiveness is a goal, the goal. Thus other measures of effectiveness are important. Model 4.2 which required an inventory before an item is ordered must be

judged in light of the value of delaying orders or discovering and ordering deficiencies, and these effects in terms of effectiveness. Wall-to-wall inventories normally require a suspension of service. This effect should also be examined.

It should be noted that the optimal inventory procedure may not be the one requiring the least number of inventories. To find the optimal procedure the number of inventories required by each procedure must be multiplied by the cost per inventory and the resulting costs compared. For example, if we fix the average record accuracy at 80 percent we get the following results from Figures 2, 3, and 4:

Method	No. Inventories Required per Year (100 items)	Cost per Inventory	Total Cost
4.1B	145	1.36 (wall-to-wall)	197.20
4.3	135	3.85 (spot)	519.75
4.4	135	3.85 (spot)	519.75

The cost per inventory data came from FMSO [5]. Here it is obvious that the two trigger schemes 4.3 and 4.4 are more effective in finding and eliminating errors. However, the relative cost data makes the wall-to-wall inventory the optimal procedure. Model 4.1A could not be included in this comparison since it investigated only the number of complete wall-to-wall inventories required to maintain a given maximum error level. However, model 4.1B represents the relative efficiency of wall-to-wall inventories. Model 4.1C and 4.2 could not be included because only 1 and 2 points, respectively, were investigated for these procedures. Regression curves were not feasible from the limited data available for these two systems.

5.3 Conclusions

Some of the results are summarized in Table VI. It can be readily seen that inventorying before ordering is dominated by the other three methods when the number of inventories required is our only measure of effectiveness. The wall-to-wall inventory is superior to the other two in the range 100 to about 82 percent. For inventory accuracies lower than 82 percent the trigger methods are best by our measure of effectiveness.

Method	90% No. of Inventories Per Year (100 items)	85% No. of Inv.	80% No. of Inv.	75% No. of Inv.
4.1	260	200	145	100
4.2	473	280		
4.3	420	230	135	95
4.4	380	210	135	95

TABLE VI

COMPARISON OF RESULTS

To determine which is best for a particular operation would require the information above to be used in conjunction with cost per inventory data. The fact that our special inventories are normally more expensive than the wall-to-wall may eliminate all opposition to the wall-to-wall inventory. From this data it appears that unless the cost of spot inventories can be brought closer in line with the per item cost of the wall-to-wall, the best method available is the complete inventory. In order to maintain a given accuracy level statistical sampling could be used to determine when the inventory should be made. The frequency that would be required could be approximated from Figure 2.

CHAPTER 6

SUGGESTIONS FOR FURTHER WORK

More study is required on error generation. Detailed information on error generation could be used in establishing programs to eliminate the cause of errors as well as updating data used in studies like this to determine optimal inventory procedures.

There appears to be room for improvement in the conduct of spot inventories. Perhaps cost could be reduced by introducing a system of the warehouse man reporting bin totals after an issue. For example, if the trigger is reached the issue document could be marked and the warehouse worker could note the balance on hand after the issue on the document. This would then be compared with the record on hand balance.

This paper assumed completely accurate inventories in almost all cases. The result of inventories leaving a residual error needs to be studied. If human factors considerations were studied it is felt that spot inventories would tend to be more accurate than complete wall-to-wall inventories. One intuitive reason would be the boredom of counting item after item without a break. The spot inventory would require a count then move to another floor or building and then count again. This will result in higher cost but perhaps more accuracy. Another reason is the availability of professional or full time counters to perform the spot inventories opposed to non-professionals doing wall-to-wall inventories. We know of only two studies that have been made on the accuracy of physical inventories, the Bayonne study [4] and the paper by Rinehart [7]. More data on physical inventory accuracy is needed. A combination

of reduced costs for spot inventories and a higher error inherent to complete inventories might overturn the conclusion reached here which assumed accurate inventories. When data is available this same type of simulation could be used to again evaluate the various inventory procedures reflecting the inaccurate inventories.

BIBLIOGRAPHY

1. Daeschner, William E., "Costs of Operating an Inventory System with Inaccurate Records," Unpublished Master's Thesis, U. S. Naval Postgraduate School, 1968.

2. Kohlhaas, P. C., "Cost Analysis of the No Inventory Policy," ALRAND Working Memorandum 136, January 1968.

3. Schrady, David A., "On Inventory Record Accuracy," Report No. NPS 55SO8031A, U. S. Naval Postgraduate School, March 1968.

4. U. S. Navy Supply Research and Development Facility, "Physical Inventory Procedures at Navy Stock Points," Unpublished Research Report, 1966 (Available through Defense Documentation Center AD-488317).

5. Crum, G. S., "Development of Physical Inventory Cost Factors, "ALRAND Working Memorandum 137, March 1968.

6. NAVSUPINST 4855.2, "Establishment of a Uniform Quality Control Program," 28 November 1967.

7. Rinehart, Robert F., "Effects and Causes of Discrepancies in Supply Operations," JORSA, Volume 8 #4, 1960.

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13. ABSTRACT

Advanced operations research procedures have provided the inventory manager a set of optimal decision rules for operating his inventory system. However, these decision rules are applied to information from inventory records that may be in error. If the records are in error the decision rules no longer insure optimal operation of the system. This paper addresses the problem of which physical inventory procedures best maintain record accuracy at a satisfactory level. Four physical inventory procedures are discussed and then tested using a Monte Carlo computer simulation of a multiple item, single warehouse, single inventory manager supply system. Discrepancies of various types are introduced into the records reflecting estimates obtained from a large naval supply center. It was found that for high demand items accuracy levels above 90 percent are not feasible. Due to the low cost per item inventoried the wall-to-wall inventory was found to be the most economical system in most situations. Suggestions are made for subsequent research.

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OPTIMAL INVENTORY PROCEDURES						